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WRDC-TR-89-3030

Volume I



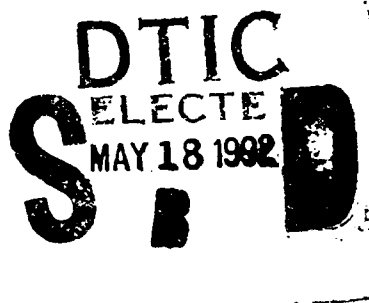
DESIGN DEVELOPMENT AND DURABILITY VALIDATION OF POSTBUCKLED COMPOSITE AND METAL PANELS

VOLUME I - EXECUTIVE SUMMARY

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NOVEMBER 1989



Final Report for Period September 1984 - April 1989

Approved for Public Release, Distribution Unlimited

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AIR FORCE SYSTEMS COMMAND
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92-13142

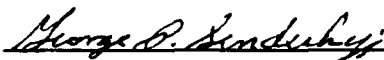



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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188		
1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED			1b. RESTRICTIVE MARKINGS N/A			
2a. SECURITY CLASSIFICATION AUTHORITY N/A			3. DISTRIBUTION/AVAILABILITY OF REPORT APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED			
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A						
4. PERFORMING ORGANIZATION REPORT NUMBER(S) NOR 89-112			5. MONITORING ORGANIZATION REPORT NUMBER(S) WRDC-TR-89-3030, VOL. I			
6a. NAME OF PERFORMING ORGANIZATION NORTHROP CORPORATION		6b. OFFICE SYMBOL (if applicable)	7a. NAME OF MONITORING ORGANIZATION FLIGHT DYNAMICS LABORATORY (WRDC/FIBE) WRIGHT RESEARCH AND DEVELOPMENT CENTER			
6c. ADDRESS (City, State, and ZIP Code) HAWTHORNE, CA 90250-3277			7b. ADDRESS (City, State, and ZIP Code) W-PAFB, OH 45433-6553			
8a. NAME OF FUNDING / SPONSORING ORGANIZATION FLIGHT DYNAMICS LABORATORY		8b. OFFICE SYMBOL (if applicable) WRDC/FIBE	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F33615-84-C-3220			
8c. ADDRESS (City, State, and ZIP Code) W-PAFB, OH 45433-6553			10. SOURCE OF FUNDING NUMBERS			
			PROGRAM ELEMENT NO. 62201F	PROJECT NO. 2401	TASK NO. 01	WORK UNIT ACCESSION NO. 80
11. TITLE (Include Security Classification) DESIGN DEVELOPMENT AND DURABILITY VALIDATION OF POSTBUCKLED COMPOSITE AND METAL PANELS. VOLUME I - EXECUTIVE SUMMARY						
12. PERSONAL AUTHOR(S) R. B. DEO, H. P. KAN						
13a. TYPE OF REPORT FINAL		13b. TIME COVERED FROM 9-84 TO 4-89		14. DATE OF REPORT (Year, Month, Day) 1989 NOVEMBER		
15. PAGE COUNT 14						
16. SUPPLEMENTARY NOTATION						
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) BUCKLING, COMBINED LOADS, COMPOSITE PANELS, COMPRESSION CURVED PANELS, DESIGN, DURABILITY, DAMAGE TOLERANCE, FATIGUE, IMPACT, METAL PANELS, POSTBUCKLING, REPAIR, SHEAR			
FIELD	GROUP	SUB-GROUP				
11	04					
19. ABSTRACT (Continue on reverse if necessary and identify by block number) The objective of this program was to develop design procedures and durability validation methods for curved metal and composite panels designed to operate in the postbuckling range under the action of combined compression and shear loads. This research and technology effort was motivated by the need to develop design and life prediction methodologies for such structures. The program has been organized in four tasks. In Task I, Technology Assessment, a complete review of the available test data was conducted to establish the strength, durability, and damage tolerance characteristics of postbuckled metal and composite panels and to identify data gaps that need to be filled. Task II, Data Base Development, was comprised of static and fatigue tests required to fill in the data gaps identified in Task I. New rigorous static analysis methods aimed at improving the accuracy of the existing semi-empirical analyses and life prediction techniques were developed in Task III. Task IV consists						
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED			
22a. NAME OF RESPONSIBLE INDIVIDUAL GEORGE P. SENDECKYJ			22b. TELEPHONE (Include Area Code) (513) 255-6104		22c. OFFICE SYMBOL WRDC/FIBE	

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19. ABSTRACT (Continued)

of technology consolidation where the results of this program were incorporated in the Preliminary Design Guide developed under Contract F33615-81-C-3208 to provide a comprehensive design guide for postbuckled aircraft structures. The comprehensive design guide was also exercised in this task, on an actual aircraft fuselage section to illustrate the methodology and demonstrate weight and cost trade-offs.

This final report consists of the following five volumes:

- Volume I - Executive Summary
- Volume II - Test Results
- Volume III - Analysis and Test Results
- Volume IV - Design Guide Update
- Volume V - Automated Data Systems Documentation

PREFACE

The work documented in this report was performed by Northrop Corporation, Aircraft Division, Hawthorne, California, under Contract F33615-84-C-3220 sponsored by the Air Force Wright Aeronautical Laboratories, Flight Dynamics Laboratory, AFWAL/FIBE. The work was performed in the period from October 1984 through April 1989. The Air Force Program Monitor was Dr. G. P. Sendeckyj.

The following Northrop personnel contributed to the performance of the contract in their respective areas of responsibility:

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R. Cordero	Data Analysis/Graphics
R. Urias	Documentation

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TABLE OF CONTENTS

<u>SECTION</u>		<u>PAGE</u>
1	PROGRAM OBJECTIVES.	1
	1.1 Introduction	1
	1.2 Program Objectives	1
	1.3 Program Summary.	2
	1.4 Documentation.	3
2	PROGRAM RESULTS	4
	2.1 Background	4
	2.2 Design Methodology	4
	2.3 Energy Method Based Non-Empirical Analysis	5
	2.4 Verification Test Data	7
3	SIGNIFICANT CONCLUSIONS	8
	REFERENCES.	10

SECTION 1

PROGRAM OBJECTIVES

1.1 INTRODUCTION

The Design Development and Durability Validation of Postbuckled Composite and Metal Panels program was initiated in late 1984 by the Air Force Flight Dynamics Laboratory to specifically address the technology needs for postbuckled composite and metal structures. This program followed an earlier Air Force Flight Dynamics Laboratory program (Reference 1) where a design methodology was developed for postbuckled composite and metal panels under simple loading conditions.

At the inception of this program an assessment of the current postbuckled stiffened panel design, analysis and applications technology (References 1 and 2) showed that several deficiencies existed in establishing a systematic postbuckling design methodology. In Reference 1 a design and analysis methodology was developed for flat and curved stiffened panels made of either composite or metallic materials, and subjected to either compression loading or shear loading. In practice, however, stiffened airframe panels are subjected to a combination of axial compression and shear loads. A semi-empirical design methodology for curved metal panels under combined loading exists (Reference 3) but has seen limited verification. The present program was undertaken to extend the Reference 1 and Reference 3 methods for application to curved composite panels under combined uniaxial compression and shear loading, and to further substantiate the metal panel design procedures.

1.2 PROGRAM OBJECTIVES

The overall objectives of the program were to develop validated design procedures and an analysis capability for curved metal and composite

postbuckled panels under combined uniaxial compression and shear loading. The specific requirements encompassed by these objectives were as follows:

1. Extend the existing semi-empirical analysis methodology (Reference 1) into a design tool for curved composite and metal panels subjected to uniaxial compression and shear loading. Account for any unique failure modes.
2. Develop a more rigorous energy method based analysis to predict the displacement and stress fields in postbuckled panels.
3. Develop a static and fatigue data base for composite and metal panel design verification.
4. Develop a fatigue analysis method for metal panels.
5. Prepare a procedural design guide. Exercise the design guide on a realistic aircraft component.

All of these requirements were accomplished during the program. The work performed to accomplish these objectives is documented in Reference 4.

1.3 PROGRAM SUMMARY

The program approach and plan paralleled those in Reference 1. At the onset, a technology review was conducted to update the data base and to clearly define the deficiencies in the static strength, durability and damage tolerance design and analysis of postbuckled metal and composite panels. The durability and damage tolerance technology assessment is documented in Reference 2. As a result of this technology assessment, a semi-empirical design methodology for curved panels under combined loading was established and a verification test program was conducted. In addition, an energy method based approach to predict the static response of postbuckled stiffened panels was formulated. This technology assessment was accomplished in Task I of the program. In Task II, Data Base Development, the tests required to fill the data gaps identified in Task I were conducted. Analytical model development

and verification was accomplished in Task III. Task IV consisted of technology consolidation where the results of the program were incorporated in a Design Guide (Reference 5) for postbuckled structures.

The composite and metal panels tested in the program were cylindrically curved and identical to the shear panels tested in Reference 1. The design methodology initially established from the technology assessment was used to estimate the buckling and postbuckling load capacities of the panels. Static and fatigue tests including several static strain surveys were conducted on the test articles. The static test data were used to verify the semi-empirical design methodology, whereas the fatigue test data were utilized to determine the fatigue failure modes and obtain load versus life data to formulate fatigue analysis approaches. The test results, in conjunction with the semi-empirical design methodology were used to update the Preliminary Design Guide (Reference 1).

1.4 DOCUMENTATION

The detailed results of the program tasks are documented in a multi-volume final report, a software user's manual, and a design guide. A list of all the reports resulting from the program is as follows:

- a. WRDC-TR-89-3030, Volume I - Executive Summary (Present Report)
- b. WRDC-TR-89-3030, Volume II - Test Results (Reference 6)
- c. WRDC-TR-89-3030, Volume III - Analysis and Test Results
(Reference 4)
- d. WRDC-TR-89-3030, Volume IV - Design Guide Update (Reference 5)
- e. WRDC-TR-89-3030, Volume V - Automated Data Systems Documentation
(Reference 7)
- f. AFWAL-TR-85-3077 - Technology Assessment (Reference 2)

The significant program results and conclusions are summarized in the following sections.

SECTION 2

PROGRAM RESULTS

2.1 BACKGROUND

An in-depth survey of the semi-empirical design methods for metal panels and their evolution into a design methodology for curved composite panels under shear or uniaxial compression loads is given in Reference 1. The shear panel and compression panel analysis methods of Reference 1 were used as the starting points for the current program. Initially, the interaction rules used for metal panels (Reference 4) were adopted to predict buckling under combined shear and compression loading. Test data were then used to verify these rules and suggest modifications where necessary. Postbuckling failure envelopes were developed by accounting for the failure modes possible under shear loading only, and under pure compression loading. Failure predictions under combined loading were based on test verified interaction criteria.

2.2 DESIGN METHODOLOGY

A complete static analysis of postbuckled structures consists of predicting the initial buckling loads, the failure or ultimate load of the panel after buckling, and the local skin and stiffener displacement and stress fields. The latter predictions are especially required for metal panel fatigue analysis. The semi-empirical methodology detailed in this section can be used to obtain the initial buckling and the failure loads. The energy method based analysis is useful in predicting the local stresses and displacements.

The semi-empirical analysis method was selected as a design tool for postbuckled structures to provide a quick, inexpensive, and reasonably accurate but conservative design methodology. The scope of this program encompassed cylindrically curved stiffened panels loaded in uniaxial longitudinal compression and shear.

The essence of the combined loading design procedure is summarized in Figure 1. As can be seen in the figure, the curved panel is analyzed for compression and shear loads independently according to Reference 1 methods. Buckling loads under combined loading are predicted using the well-established parabolic interaction rule for metal panels. Failure analysis required consideration of failure modes under shear and compression acting independently and those due to the interaction of the loads. The failure modes affected by combined loading were stiffener crippling, and skin rupture under tensile loading. A linear interaction criterion was developed to predict stiffener crippling under combined loads and skin strength was determined from a principal strain analysis and the maximum strain criterion. The design procedure was coded in a PC-based computer program called PBUKL to enable rapid design of post-buckled panels.

2.3 ENERGY METHOD BASED NON-EMPIRICAL ANALYSIS

The semi-empirical analysis of postbuckled panels described above does not yield the stress and displacement fields required for a fatigue analysis of the panels. Furthermore, with the semi-empirical analyses, the complex mechanisms of load transfer before and after buckling such as the interaction forces between the stiffeners and the web, and the effect of stiffness changes in the postbuckling range, cannot be modeled. Thus, development of a non-empirical analysis to accurately predict the postbuckling behavior of the panel as a whole, including the web and the stiffeners, was undertaken.

Based on the survey of non-empirical static analysis methods conducted in Reference 1, the total postbuckling behavior of stiffened panels loaded in compression or in shear was modeled using the principle of minimum potential energy. The problem was formulated for a single bay including the skin, stiffener, and the ring. The stiffeners and the ring are assigned lumped axial and flexural stiffnesses. The skin is modeled as a curved, anisotropic laminated plate with a balanced and symmetric layup. A small imperfection was also included in the out-of-plane displacement functions. The in-plane and out-of-plane displacements were assumed and consisted of a series of admissible trigonometric functions with unknown coefficients. The

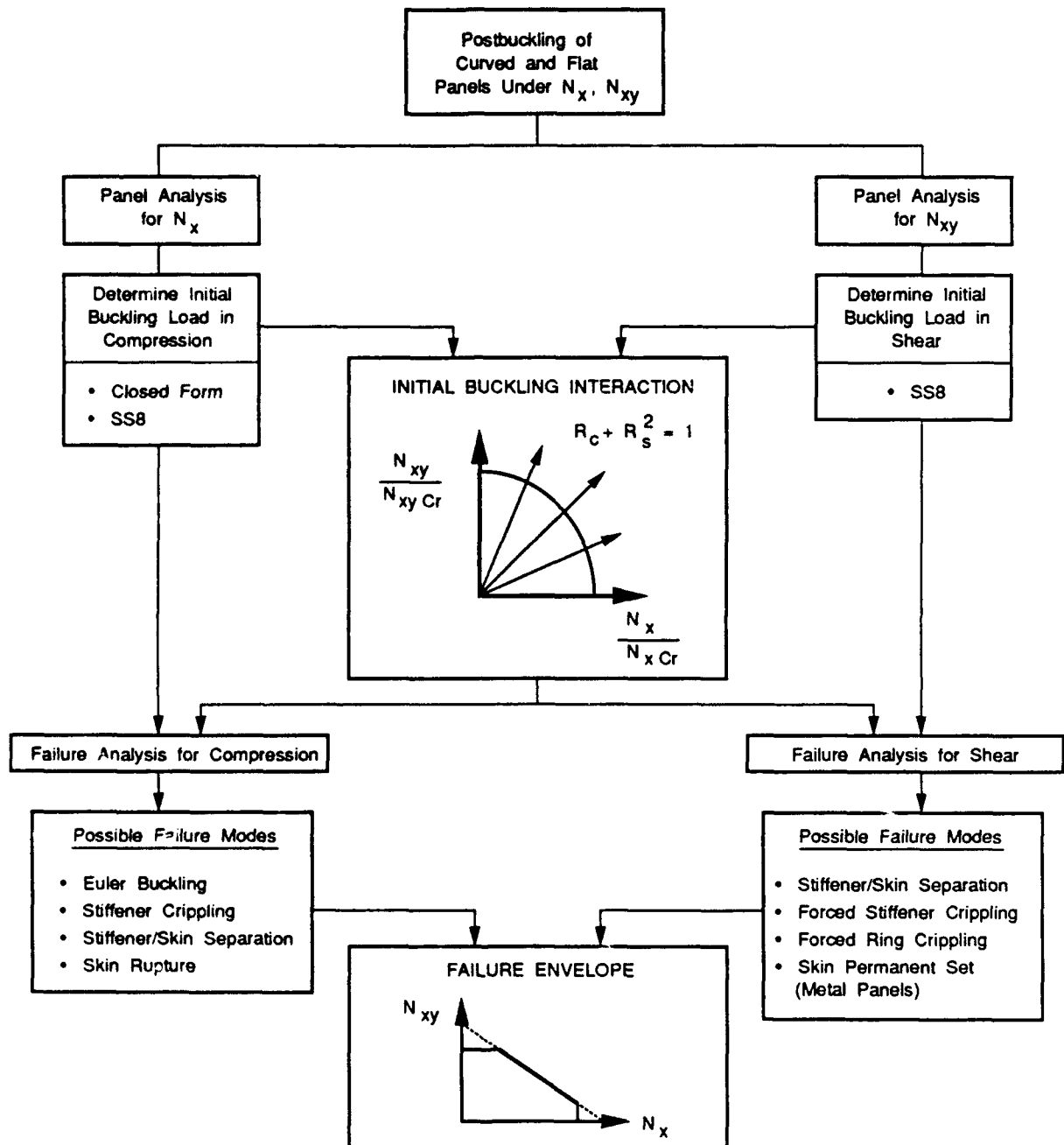


Figure 1. Semi-empirical Analysis Approach for Postbuckled Stiffened Panels Under Combined Loading.

unknown coefficients were determined by minimizing the total potential energy of the single bay panel.

The feasibility of this approach was established by first obtaining a single mode solution to the problem. The single mode solution was programmed on a personal computer and proved to be very valuable in selecting the most dominant postbuckling modes of the panel. These modes were then used in a multi-mode solution to obtain the panel stresses and displacement fields with greater accuracy. The multi-mode solution is coded in a computer program called PACL (Reference 7).

2.4 VERIFICATION TEST DATA

A total of 20 metal and composite panels were tested in the program. Twelve of these panels (four composite and eight metal) were tested under fatigue loading and the remainder under static loading. The static test data were used for analysis verification and the fatigue data to develop a life prediction model.

SECTION 3

SIGNIFICANT CONCLUSIONS

The significant conclusions from this program are summarized below.

1. The semi-empirical static design methodology developed in Reference 1 for postbuckled composite and metal panels under pure shear or pure compression loading was extended to panels under combined uniaxial compression and shear loads.
2. The methodology was coded in a computer program (PBUKL) for rapid iterative design of composite and metal panels.
3. Ultimate panel strength predictions based on the semi-empirical analysis for composite and metal panels were found to be very accurate and well suited for design purposes.
4. Stiffener and skin separation in composite panels was the observed failure mode under static combined uniaxial compression and shear loading.
5. For metal panels under combined compression and shear loading stiffener crippling was the dominant failure mode.
6. Postbuckled metal panels were fatigue sensitive and durability considerations can severely limit the postbuckled operation range of metal panels.
7. Composite panels demonstrated a high fatigue threshold relative to the initial skin buckling loads. Composite panels showed a greater sensitivity to shear dominated fatigue loading as compared with compression dominated fatigue loading.

8. The fatigue failure mode in composite panels was separation between the cocured stiffener and the skin. In particular, the region at the intersection of the stiffener and the ring was vulnerable to this failure mode.
9. Program PACL is an efficient and cost effective tool for detailed non-empirical analysis of postbuckled metal or composite panels. As compared to some finite element programs PACL is 20 times faster.

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